



Rainfall Across the Globe

**Precipitation plays an
important role in
many environmental
phenomena**

Precipitation

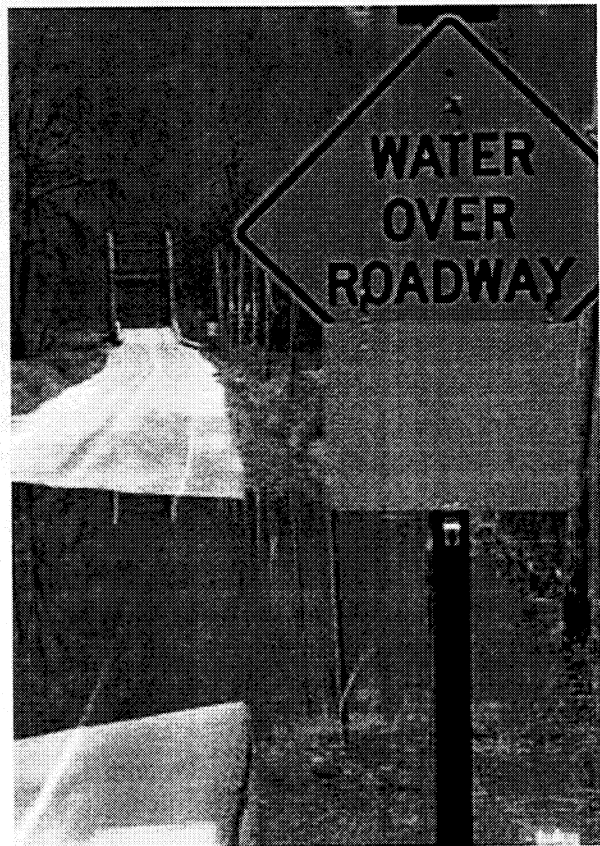
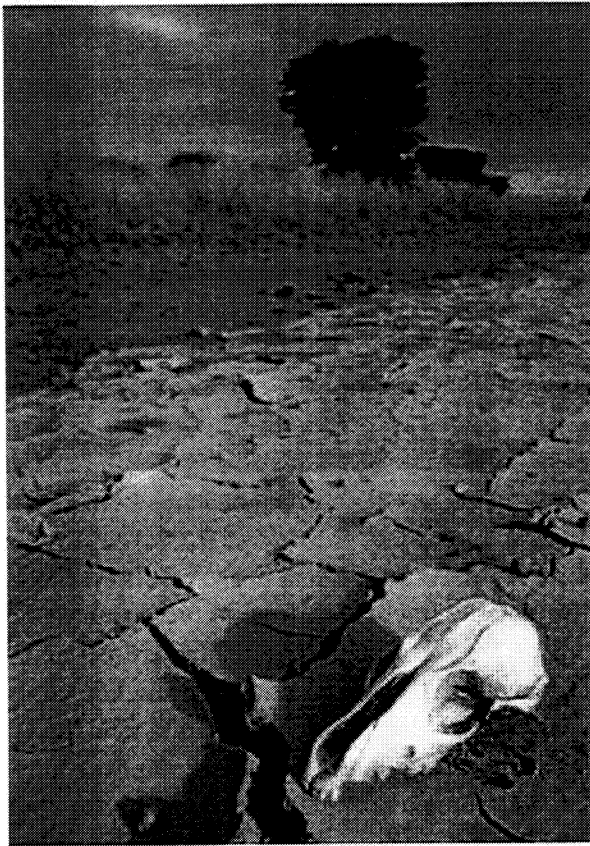


The numerical simulation of precipitation helps scientists understand the complex mechanisms that determine how and why rainfall is distributed across the globe.

Simulation aids in the development of forecasting efforts that inform policies regarding the management of water resources. Precipitation modeling also provides short-term warnings for emergencies such as flash floods and mudslides.

Just as precipitation modeling can warn of an impending abundance of rainfall, it can help anticipate the absence of rainfall in drought. What constitutes a drought?

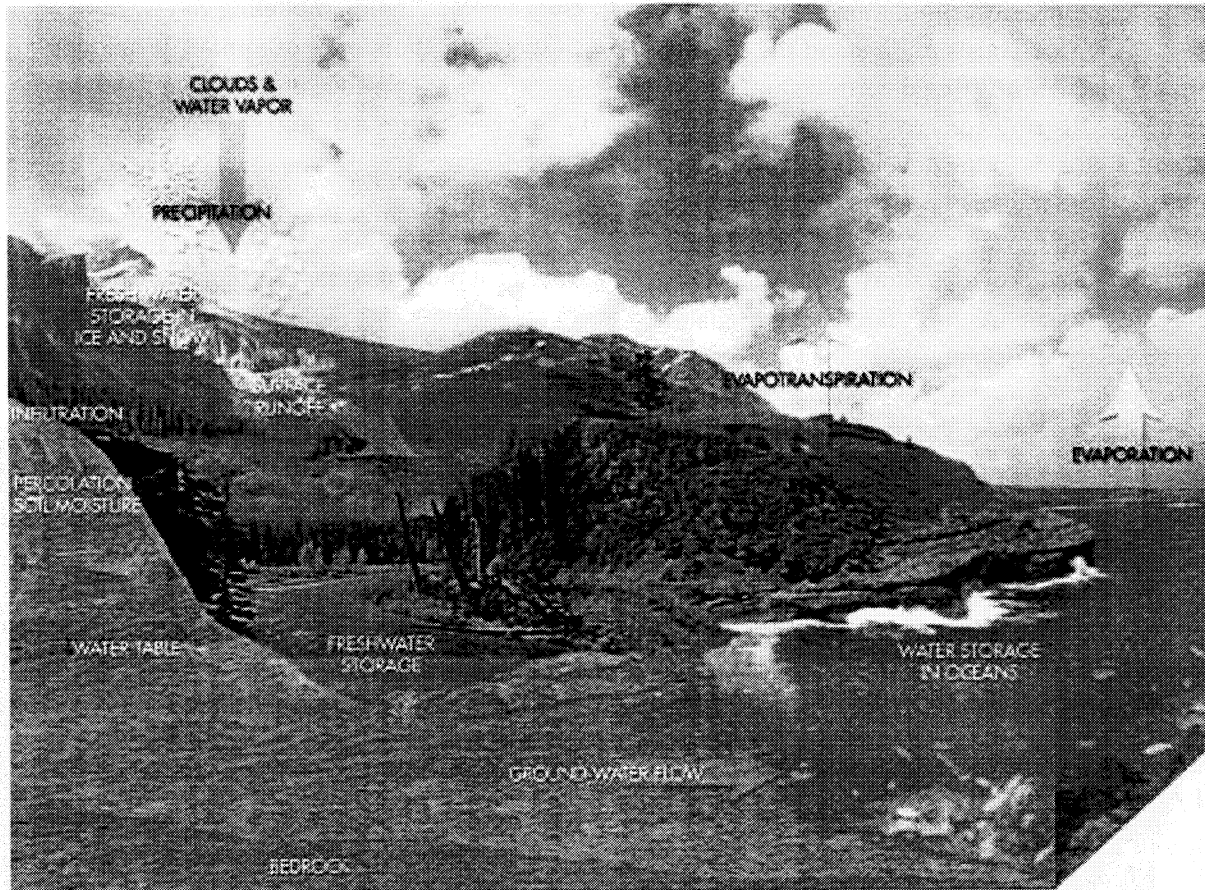
- A *meteorological drought* simply means that an area is getting a significantly lower amount of rain than usual over a prolonged period of time.
- An *agricultural drought* is based on the level of soil moisture.



As we learn more about what drives precipitation, we can anticipate extreme fluctuations in rainfall, leading to droughts and floods.



Precipitation



Precipitation is a vital link in the hydrological cycle that moves water through land, sea, and air.

- A *hydrological drought* focuses on lower precipitation levels that reduce bodies of water on the surface, such as lakes and streams.
- A *socioeconomic drought* takes into account human activities, such as the construction of dams and terrain shaping, that alter the distribution of surface water.

A numerical model for drought prediction is shaped by the drought criteria that are selected. The meteorological definition of drought focuses primarily on the amount of precipitation. The agricultural and hydrological definitions require model components not only for precipitation but also for soil moisture absorption and evaporation of water. The socioeconomic view of



Monsoons

For people who live in the Pacific Ocean's monsoon region, the arrival of monsoon rainfall in July and August means the end of the long dry season. A monsoon that is either too strong or too weak may lead to flooding or drought. To help predict monsoon strength and to understand the interaction between monsoon and other atmospheric phenomena, we must understand why monsoons exist, what accounts for the circulation field of a monsoon, and why monsoon onset is abrupt.

The two types of monsoon are summer and winter. Despite their names, both monsoons take place during the July-August season. The main difference is in their location. The summer monsoon takes place more than 10 degrees north of the Equator, where the season is summer. Likewise, the winter monsoon is located south of the Equator, where July is in the middle of winter.

The summer monsoon is a continental-size convective system, characterized by a large precipitation region. This region is identified as an off-equatorial *intertropical convergence zone* (ITCZ). The strongest summer monsoons occur near southern Asia. Monsoons also occur near Australia, North and South America, and Africa.

In a northern summer monsoon, the prevailing winds at the low levels are from the southwest. At high levels, the wind direction reverses. This configuration produces a large vertical wind shear that does not occur elsewhere in the tropics.

Just as low-level winds run southwesterly in the northern summer monsoon, they run southeasterly in the southern winter monsoon. Ancient mariners depended on this seasonal change of prevailing wind to sail between India and Africa.

In the monsoon onset process, the ITCZ shifts from near the Equator to more than 10 degrees away in days. Compared with the movement of the Earth's tilt toward the Sun, this change is rapid.

Like any large-scale circulation, the monsoon is highly influenced by the Coriolis force. This force, which is created by the Earth's rotation, moves to the right of wind direction in the Northern Hemisphere and toward the left of wind direction in the Southern Hemisphere. At the low levels, the air mass flows toward an ITCZ in the Northern Hemisphere from the other side of the Equator. The wind direction, which is influenced by the Coriolis force, enters the northern hemisphere from the southeast. After the air mass crosses the Equator, the direction changes to a southwesterly flow. Wind flow also comes from the north of the ITCZ, but its strength is much weaker.

At upper levels, the airflow must return in the opposite direction. The circulation field and the convective heating in the ITCZ precipitation region interact; yet, neither causes the other.



drought, with its dependence on human action, may be the most difficult version to quantify in a simulation.

Accurate precipitation modeling can also improve understanding of other environmental issues. For example, rain droplets absorb certain airborne pollutants and remove them from the atmosphere when they fall to the ground. Therefore, models of atmospheric composition can benefit by incorporating a precipitation component.

As scientists studied global precipitation, they noted a correlation between the amount of rainfall in particular areas of the world and other weather conditions. For example, in certain regions, droughts are strongly associated with the warm or cold phase of the El Niño-Southern Oscillation cycle. Indeed, evidence links global patterns of sea surface temperature (SST) to regional precipitation patterns across the decades. However, as evidenced in the second research profiles that follows, SST explains only a portion of precipitation variability.

Precipitation simulations are usually compared to actual rainfall measurements to test their accuracy. These measurements can be derived from

rain gauges at specific points on the ground. Remote sensors based on radar and satellite instruments are a more practical means of collecting data to estimate rainfall over larger regions.

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Research Profile: The Role of Landmass in Monsoon Development

Investigator:

Winston Chao, NASA Goddard Space Flight Center, Climate and Radiation Branch

Since the 17th century, a fundamental belief has prevailed that the basic cause of a monsoon is the contrast in surface temperatures between the continents and the oceans. Research using general circulation model (GCM) experiments demonstrated that this belief should be changed.

In an experiment in which the researchers replaced the landmasses of Asia and Australia with ocean, the simulated Asian and Australian monsoons remained largely intact. The figures on page 62 show the monsoon precipitation averaged for the month of August in a 4-year model integration. The upper panel shows the control experiment with the continents intact. For the lower panel results, ocean replaced the continents.

Further experiments showed that in the Asian monsoon, the change resulting from the replacement of continents with ocean was caused more by the removal of topography than by the removal of land-sea contrast. Whereas land-sea contrast played a minor modifying role in the Asian summer monsoon, it played an important role in the African and South American summer monsoons. However, that role was not irreplaceable. If an ocean with a high enough SST replaced Africa or South America, the monsoon

remained, even without the presence of a continent.

To understand why monsoons exist is to understand why the ITCZ exists in particular off-Equator regions during the summer. In an aqua-planet model with zonally uniform SST, the ITCZ is zonally uniform and located at the tropical latitudes where SST is high. The solar energy absorbed by the surface at these areas heats the air above and controls the location of convective precipitation.

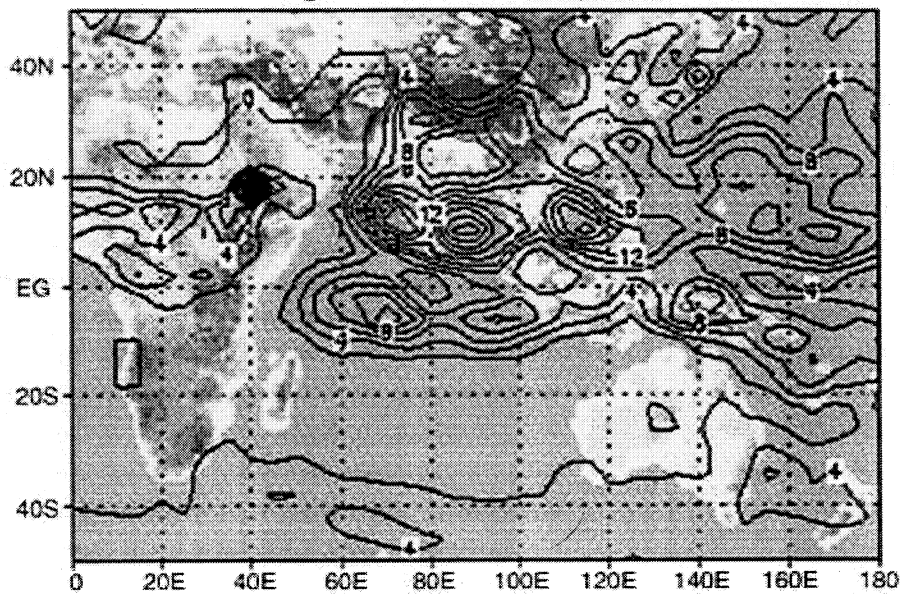
The SST is only one factor that determines the location of the ITCZ. Another influencing factor is the Earth's rotation, which pulls the ITCZ toward two different latitudes at around 13 degrees north and south of the Equator. Therefore, ITCZ is often observed at both locations.

When researchers varied the distribution of SST in the simulation, the ITCZ was no longer zonally uniform but concentrated somewhat to the west of the longitudes where SST was highest. The model then gave a precipitation and circulation field that was very close to real-world observations. Therefore, researchers concluded that landmass is not a necessary condition for monsoons.

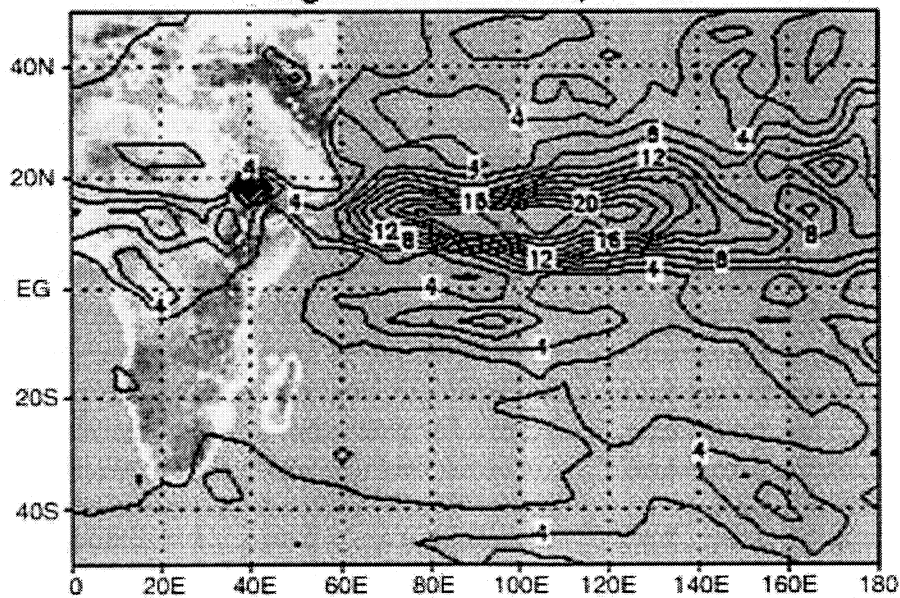


Precipitation

August Mean Precipitation



August Mean Precipitation



Monsoon precipitation levels were calculated for two drastically different environments. In one simulation (top), the land remained in place. In the other (bottom), the landmasses of Asia, Australia, and the Pacific Islands were replaced by ocean. When the land was removed from the model, the Asian and Australian monsoon regions still existed. However, monsoons did not extend into the southern China region.

Precipitation



The research project also showed that the monsoon process is similar to the flipping of a light switch. When a switch is pushed gently and persistently, it flips from one stable state to another very quickly. Likewise, the ITCZ is pushed toward the poles by the seasonal meridional movement of the peak of the SST. This movement is countered by another force that is produced by the Earth's rotation. When the latter force finally gives way, the ITCZ suddenly jumps away from near the Equator, and monsoon onset occurs.

Chao's numerical experiments with an atmospheric GCM have demonstrated the monsoon onset process. The circulation field associated with the ITCZ determines the equatorial surface winds that, in turn, determine SST near the equator. Therefore, study of monsoons or the ITCZ is highly relevant to the study of El Niño. The experiments used the Goddard Earth Observing System (GEOS) atmospheric GCM, running on the NCCS Cray SV1 supercomputer.



Research Profile: The Relationship Between Precipitation and Sea Surface Temperature on Decadal Time Scales

Investigators:

Siegfried Schubert, Max Suarez, and Philip Pegion, NASA Goddard Space Flight Center, Data Assimilation Office

This research project examined the possibility of a connection between SST and precipitation on multiyear time scales. In particular, the research focused on rainfall over the Great Plains region of the United States during the summer months.

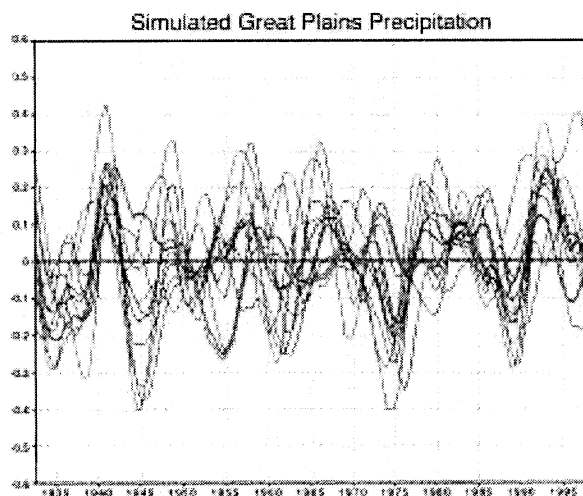
The researchers ran nine simulations of precipitation, spanning the years 1930 through 1999, using the NASA Seasonal-to-Interannual Prediction Project (NSIPP) atmospheric GCM. They used 64 of the NCCS Cray T3E computer's 1,360 processors to conduct these 70-year runs. The associated data was stored on the NCCS's Sun E10000 UniTree storage system.

A Cray support member from the NCCS helped speed up the progress of this effort. He located a default setting that prevented the model code from running at full speed. He also showed the researchers how to buffer the data output and speed up run times even further. These efforts reduced run times by 13 percent. Overall, the Cray T3E calculated more than 225,000 days of model simulation in only 700 days of computing time, spread across the 64 processors devoted to this project.

Each simulation run was forced with the same set of observed SST measurements. However,

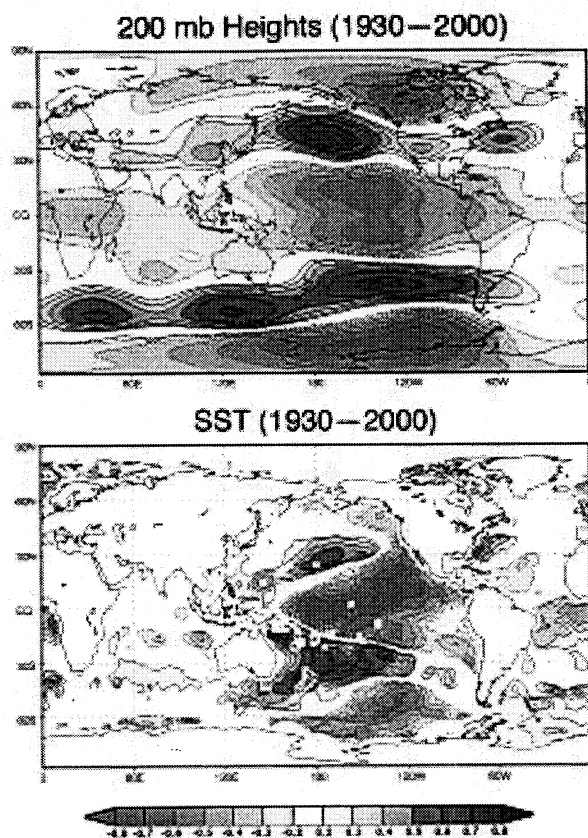
initial atmospheric conditions were different. If the same SST data produced similar patterns of precipitation over the Great Plains, even with different atmospheric conditions, the results would demonstrate a link of predictability between SST and precipitation.

The nine runs showed different levels of rainfall; therefore, overall this experiment did not indicate a strong link between SST and precipitation. However, the simulated results did share similarities with actual rainfall records. Nearly all the



This graph lays out nine simulations of Great Plains rainfall. The black lines represent the individual simulation runs, and the green line is the ensemble mean. The red and blue lines represent various observational estimates.

Precipitation



These color maps indicate the negative correlation between certain meteorological measurements and calculations for precipitation over the Great Plains region. The bottom map shows SST correlation, and the top map shows the correlation for the altitude at which air pressure reaches a measurement of 200 millibars (mb). Because this project is concerned with the absence of precipitation, negative correlations are mapped.

runs indicated dry conditions during the 1930s, followed by wet conditions in the next decade. This result matches the infamous "Dust Bowl" drought of the Great Depression era.

In contrast, only one of the nine simulations replicated conditions similar to another major Great Plains drought that took place in the 1950s. In fact, some simulation runs produced multi-year droughts even when no anomalies in SST levels were present.

After they completed the simulation runs, the researchers mapped the correlation between Great Plains precipitation and SST. The correlation revealed a decades-spanning SST pattern across the Pacific Ocean that is linked to rainfall variations in the Great Plains region. When the Pacific pattern is in its warm phase, the Great Plains region gets more precipitation than usual. Conversely, drought conditions tend to occur in this area when the Pacific SST pattern is in a cold phase. Several additional atmospheric GCM runs confirmed this correlation.

Overall, the project results suggested that the ability to predict Great Plains droughts depends in part on the ability to predict the long-term behavior of the Pacific SST pattern.